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THEORIES OF ACCIDENT CAUSATION

Prepared by Michael D. Harvey, Ph.D.
Under contract to the Research Branch

Alberta
WORKERS' HEALTH, SAFETY
AND COMPENSATION
Occupational Health and Safety Division

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FOREWORD

The mission of the Alberta Occupational Health and Safety Division is "to prevent work-related accidents and ill health and to promote occupational health and safety in Alberta". In fulfilling this mission, division staff depend upon information obtained from accident investigation reports and claims submitted to the Workers' Compensation Board.

The significance of accident information to the division has led to increased interest in developing more effective ways to collect, interpret and use accident data. Paralleling this trend has been a growing awareness that issues related to accident data cannot be separated from their theoretical context. Dr. Herbert Buchwald, Managing Director of the Occupational Health and Safety Division, first articulated the need for a study which would formally examine the causal assumptions of different theories and models of the accident process. Dr. Buchwald appointed a project team, comprised of Judith Evans, Lynn Hewitt, and John McDermott, to further develop the concept for the study and to commission a consultant (Michael D. Harvey) to prepare the present theoretical review.

In his report, Dr. Harvey identifies and describes the major theories of accident causation which have historically guided the occupational health and safety field. A subsequent report will examine the implications of these theories for accident investigation strategies.

The advice and assistance of staff members in Occupational Health Services and Work Site Services is gratefully acknowledged. Special thanks are extended to Laurie Fraser of the Occupational Hygiene Branch and Brian Alleyne of the Medical Services Branch.

Research Branch
January, 1985

EXECUTIVE SUMMARY

Theories of accident causation have displayed an historical progression, from simple, single factor theories to complex, multiple factor systems approaches. This progression reflects both the increased research sophistication of safety professionals and academics as well as an increased borrowing of ideas from other disciplines (e.g., medicine, sociology, psychology, management science, and education).

Because most of the theorizing about the causes of accidents has been directly motivated by an applied concern with accident prevention, there exists a fuzzy conceptual boundary between "theories of accident causation" and "accident investigation systems". Results of accident investigations and theory-guided research into accidents are potentially complementary in that accident investigations can uncover regularities surrounding accident occurrence (e.g., type of machine, characteristics of the accident victim), which can then be investigated by controlled, theory-guided research. Theory-guided research can potentially reveal important new types of information to be gathered in accident investigations.

To date, there have been few research studies based on any of the major theories of accident causation. Therefore, evaluation of these theories can be made in terms of their conceptual properties only.

<u>Single factor theories</u>. Single factor theories, which identify one (or a few) aspects of the accident as the "cause" and propose one (or a few) remedies as the solution, provided the earliest explanations of accident causation. Examples of

these theories include the *accident prone worker*, *psychodynamic (worker motivation)*, *social-environment* and *domino theories*.

Multiple factor theories. Multiple factor theories represented an advance over single factor theories in that they formally acknowledged the possibility that many factors could potentially cause an accident to occur. The *epidemiological approach* to accidents (the most important example of the multiple-factor theory), describes accidents in terms of host (e.g., age and sex of victim), environment (e.g., working conditions) and agent (i.e., the physical "cause"), with a view toward identifying factors contributing to the accidents and the population at risk. While the epidemiological approach has been useful in studying diseases, it is unclear how successfully the host-environment-agent analogy can be applied to accidents.

The epidemiological approach explicitly recognizes that accidents may result from the *interaction* of three types of variables. However, the theory provides little guidance to the researcher as to which host, agent, and environment variables and which interactions are most promising to study.

The systems approach. Systems theories of accident causation focus on the interaction or match between the *individual* (e.g., psychological processes such as perception, memory, and decision making), and the demands that the *work task* places on the individual. Other variables (e.g., personality, age, energy transfer, etc.) are of interest only by virtue of their relationships with these psychological or task variables.

According to systems theory, accidents result from a mismatch between the performance of the machine or environment, and the performance of the worker/operator, whether or not damage or injury occurs. Thus, systems theory concerns itself with the interaction, feedback, and adjustment between man, machine and environment. Examples of systems theory applications from the literature include the *Surry model*, *Andersson et al's extension of the Surry model* and *Hale and Hale's* expectancy, skill and decision model. Other applications of the general systems model have been developed by *Smillie and Ayoub*, *Corlett and Gilbank*, and *Saari*.

Summary and Conclusions

Single factor, two factor and epidemiological theories have generally failed to explain the nature of the interaction among accident causes and have concentrated on variables which are correlated with accident occurrence but cannot themselves directly cause accidents. The more recent systems theory approach begins with an analysis of how man and machine (or environment) interact, and focuses on primary human factors such as perception, memory, judgment and motor skills. Factors identified by the earlier theories are considered to be secondary because of their indirect causal influence through these primary variables (e.g., age affects response time).

Implications for investigation. In order to understand the cause of an accident, systems theory points to the need to gather information on the normal and abnormal states of the operating system. Such base rate information is critical for understanding the relationship between accident occurrence and other variables of interest.

Implications for prevention. Systems theory suggests that accident prevention efforts can be directed at either the operating system or the operator. It suggests that accidents can be avoided by increasing the reliability and decreasing the variability of machine performance and designing the machine so that it provides clear and accurate danger cues to the operator. The theory also suggests many ways to improve the operator's safe and efficient task performance.

Implications for basic research. It is proposed that priority areas for basic research include: the development of methods for observing and recording the operating system, and for determining the danger cues; determining human limits with respect to perception, recognition, recall, risk judgments and performance; and distinguishing between primary and secondary human factors.

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THEORIES OF ACCIDENT CAUSATION

Theories of accident causation range in scope from the simple, single factor theory to the increasingly complex multiple factor systems theory approach. This increasing range in scope follows an historical trend: early writers proposed single factors as causes (for example, either person faults, machine faults, or chance), while the systems theory approach, which is a recent development, includes many factors as well as their interactions. This progression is an understandable outgrowth of many forces, including increased research sophistication among accident researchers and safety professionals, increased adoption of theories and concepts from other disciplines, and the increasing sophistication of the disciplines being borrowed from.

Borrowing from other disciplines is a salient feature of accident theories and models; concepts have been borrowed from medicine, sociology, psychology, management science, education, and others. This borrowing is due largely to the applied nature of accident research; accidents have not been considered an intrinsically interesting topic of research in themselves, that is, the research and theorizing has not been motivated primarily by curiosity. Rather, the impetus for theory and research in this area is the human and monetary costs associated with industrial accidents. The accident is a social problem, and researchers from a variety of disciplines have gravitated toward it, bringing with them their own perspectives on the issue, their own theories, methods, and preferred solutions. As a consequence there is a diversity of opinion regarding the issues, the methods, and the important concepts.

This diversity is a mixed blessing. On the positive side, it allows for a broad choice of concepts, models, and theories to employ in the research. But so far the negative aspects of diversity have out-weighed the potential advantages, with the result that there is no agreed-upon common language for theory and research, and as a consequence there is little cross-referencing in the literature; each person tends to write to his/her own discipline rather than to the whole enterprise. However, this criticism may be unfair, since the significant advances in theory and research on accidents are quite recent, and to expect integrative work or even some coherence within the literature may be premature at this stage. Regardless, the present state of affairs in the literature makes the task of reviewing theories of accident causation a complex and difficult one.

The applied nature of the area posed another problem for a review of theories, namely, that there exists a very fuzzy boundary between what are referred to as theories and what might best be described as investigation systems. As an applied discipline, accident researchers are called upon to determine the cause of a particular accident, and the literature which speaks to this task will typically list many variables, the presence or absense of which are to be reported. The accident investigator then, by some means, identifies one or more of the variables as probable causes of the accident. This is essentially a _post hoc_ analysis of an accident; the investigator cannot observe the accident in progress, but must reconstruct it and the conditions surrounding it in a variety of ways. Retrospective accounts by the

persons involved can provide general information about the nature of the task, the state of the machinery, and the condition of the operator at the time of the event, and records can provide some information about the operating history of the machine and its operator. But in most cases a complete description of the accident event itself cannot be obtained (the persons involved cannot reliably report on the events immediately prior to the injury or damage, nor can they report well on their perceptual, cognitive, and judgmental processes). The investigator, then, can only obtain a large array of secondary descriptors of the event. With a sufficient number of such accident reports an investigator might be in a position to identify possible correlates of accidents of a certain type, and to identify problem areas in need of closer study, but only rarely can a cause be identified for any given accident.

A theory, in contrast, begins with some _a priori_ assumptions about the nature of accidents and some hypotheses as to the causes of an accident, and from this framework generates a list of potentially important variables, the true values of which need empirical test. A theory, then, directs accident research by identifying those variables that must be included in it, and can identify the appropriate conditions or groups to be contrasted in order to test the theory adequately (for example, a theory can indicate the nature of the control group to be included in order to test some causal hypothesis).

These two sub-areas of the discipline -- accident theory and accident investigation -- are potentially reciprocal; each could benefit from the work of the other, and each occasionally merges with the other.

For example, accident investigation might identify a certain regularity of occurrence in accidents (e.g., a particular machine, a particular process, etc.). Theory-driven research might then be directed toward this class of accident in order to understand the relationship between the secondary indicator and the accident rate. This theory-driven research could in turn identify new observations to be included in an accident investigation. The fuzzy boundary between theory and systems for investigation produced instances during the review process of articles that purported to be models or theories of accident causation, but which turned out on closer inspection to be accident investigation systems.

Research related to industrial accidents has been guided largely by the applied concerns rather than by theoretical issues, and therefore is unsuited for the task of evaluating the theories of accident causation. There is very little theory-guided research in this literature with which to evaluate the theories that have been proposed, and this is especially true for the more recent theories. Therefore, the evaluation of theory in this paper will in most cases be conceptual rather than empirical.

A. <u>Single Factor Theories</u>

Included in this section are the early theories that typically identified one aspect of the accident as the cause, and proposed a single remedy as the cure. The majority of these theories are rarely used explicitly today, but they have not been disposed of easily, and the ideas expressed by them still enjoy considerable public support. In addition, the multiple-factor theories which gradually replaced the simple theories often reserved a niche for the old single factor theory.

1. The accident prone worker.

In the original statement of this theory (Greenwood and Woods, 1919; Newbold, 1926), it was proposed that accidents were not randomly distributed among persons, but rather, that certain persons were more likely than others to have accidents. The theory, then, identifies the individual in some way as the cause. These researchers presented considerable data which showed that a small number of persons suffered more accidents than would be expected by chance. It was suggested at this time that personality characteristics might differentiate this "greater than chance" group from the general population, but Newbold, and Greenwood and Woods were careful to point out the obstacles in the way of such a conclusion; for example, the problem of equal exposure to risk.

These cautions, however, were not heeded by later researchers (eg., Farmer and Chambers, 1939) who treated the accident-prone personality type as a fact, and the search was on for a measure or set of measures that would predict which individuals would have multiple

accidents. The important assumption for this theory was that accident-proneness was a stable, innate characteristic of some individuals; in other words, an accident-prone person would have a higher accident rate regardless of task, life circumstance, experience, and so on. But the research never supported this assumption. Despite the initial caveats, exposure to risk was seldom controlled in the research. Also, the accident-prone group, as identified by a higher than expected accident rate during one time period, changed its composition during the next time period; that is, there was considerable temporal instability in the accident rates of individuals (see research cited in Arbous and Kerrick, 1951). This instability of accident rate (the criterion measure in the search for the accident prone personality type) severely limits the ability of any personality variable to predict an individual's membership in an accident prone group.

Extensive criticism of the concept in the early 1950's should have eliminated accident proneness as a theoretical account of accidents (Arbous and Kerrick, 1951), but in 1969 J. Surry perceived the need to reiterate those criticisms. The idea that some people, by their personal nature, are involved in accidents is an appealing one, because it implies that a simple solution to accident rates is to identify the criteria that would enable one to screen out persons who are identified as accident prone. The theory has lost much of its force because it has failed to deliver this simple solution. But this is not to deny the value of identifying those persons who suffer multiple accidents. Shaw and Sichel (1971) argue that accident proneness be retained as an

indicator of a mis-match between the worker and the task, However, this use of the concept is very different from the original use, since Shaw and Sichel use accident-prone only to mean multiple accidents, without any implication that personality factors are involved.

2. Psychodynamic theory.

Unlike the above approach, this theory and approaches like it implicate the motivations of the injured worker as the cause of the accident. The psychodynamic approach, based upon Freud's theory of personality dynamics, is the clearest statement of the theory of a motivated accident. The hypothesis is that an accident is the result of an unconscious wish or desire, which is fulfilled symbolically through the accident. The accident is, in some sense, desired by the victim. In principle, the solution to accidents becomes a simple matter of re-directing the means of wish-fulfillment to a more acceptable outlet, or eliminating the destructive desire entirely by means of psychoanalysis. However, psychodynamic theory is unworkable as a theory of accidents since it provides no means for verifying that a particular motive caused a particular accident. It remains, I think, only a curiosity among theories of accident causation.

I bother to mention the psychodynamic approach at all because it has an interesting implication. Unlike the accident prone individual, whose character faults are presumed to be innate, stable, and unmodifiable, unconscious motives are subject to change. In other words, the theory acknowledges that persons who suffer more than their share of accidents can be changed into accident-free workers. The

general implication is that one could take members of the "accident-prone" group and reduce its accident rate through some form of education or retraining, rather than eliminate the group from the work force entirely.

While the psychodynamic approach was impractible as a retraining method, other motivation-type theories could be proposed that offered more practical retraining solutions. For example, simple hypotheses that identified carelessness or poor attitude as the cause of accidents share a kinship with the psychodynamic approach, in that they identify worker motivation, broadly speaking, as the cause, and implicate training or education as the remedy. That carelessness and poor attitude are the causes of industrial accidents are accepted as truisms within the literature, and it is impossible to argue that these factors are not implicated in at least some accidents. However, it is clear that these factors do not tell the whole story; accidents often enough happen to persons whom co-workers and supervisors can describe as careful and dedicated. In other words, the correlation between the predictor and the criterion are apt to be too low to account for much of the variability in accident occurrence.

3. Kerr's social-environment models.

Kerr (1957) introduced two variables relating to the personal and the work environment which he felt complemented accident-proneness as causes of accidents. Kerr claimed that these new factors would account for all accidents that could not be accounted for by the proneness concept. These new variables described the freedom allowed within the

workplace, and the life-stress experienced by the worker, as factors that would decrease and increase, respectively, the individual's accident rate.

The goals-freedom-alertness theory held that the freedom to set one's own reasonably attainable goals is accompanied by high quality worker performance. The idea is that a worker who is able to make work-related choices, judgments, decisions, and so on (that is, he/she has work freedom) will be more alert on the job, and alertness avoids accidents. The lack of work freedom produces low quality performance, and low quality performance, according to Kerr, produces accidents. The basic argument, then, seems to be that a rewarding work environment promotes safety. The vagueness of the definitions and the range of items that could be considered rewards in the workplace (Kerr suggests, for example, the freedom to decorate one's work station) make this theory difficult to test. At best, this is a theory of how to promote safety rather than a theory of accident causation.

The adjustment-stress theory held that unusual or distracting stress on the individual increases liability to accidents and/or other low quality work performance. These stresses are seen as temporary conditions that decrease worker alertness, and could include a change in job, a new supervisor, a marriage, death, birth, divorce, disease, and so on. Kerr also lists purely environmental sources of possible stress -- noise, poor lighting, extremes of temperature -- as well as ambiguous sources (eg., time constraints), and views the failure to any of these as a potential cause of an accident.

These two theories, as presented by Kerr, merely list a host of factors, without stating either how or when each might be relevant (he does not consider, for example, that people will differ in the manner they choose to express their workplace freedom, or that people will differ in the manner and efficiency with which they cope with his list of stressors). Only intuition supports Kerr's claim that these factors affect alertness (this concept is never defined), and the subsequent probability of an accident. While Kerr's approach to accident causation did serve to highlight the possible contributions of "quality of life" variables, his theories are poor guides at best for an improved understanding of accident causes.

4. Heinrich's Domino Model, and variations.

The domino model describes a causal chain ending in an injury. The chain begins with (1) social and environmental factors, that cause (2) personal faults (carelessness, ignorance), that cause (3) an unsafe act or a physical/mechanical hazard, that causes (4) the accident event, that results in (5) injury to the person. This chain is likened to a row of standing dominos, in which the collapse of one is determined only by the collapse of the previous one.

This model makes the strong claims that (a) an injury is always the result of an accident (this, I believe, defines "accident" for the domino model), (b) that an accident is always the result of an unsafe act or a mechanical hazard, (c) that these are always the result of person faults, and so on. Conversely, the model claims that if one performs an unsafe act, there will be an accident, and if there is an

accident, there will be an injury. These strong statements are clearly false; the relationship between these chained causes are probabilistic, and are not determined in an absolute sense. Only some accidents cause injury, and only some unsafe acts cause accidents, etc. The domino model is far too simple for a complete understanding of accidents.

Several variations and adaptations of this model have been proposed, primarily for use by management safety personel. The appeal of the model for safety programmes is its assumption that removing one domino only will eliminate accidents (by breaking the chain). These models, and the safety programmes developed from them, have focussed upon the middle domino -- unsafe acts and mechanical hazards -- as the one to be eliminated. While this may be a practical choice, there is clearly no theoretical reason for it, since the theory gives equal causative power to each domino. The revised models (see Heinrich, Petersen, and Roos, 1980), regardless of the simplicity or complexity of the diagrams used to describe them, are invariably lists of factors that may contribute to an unsafe act or hazard, and all fail to specify the relationships among the members of the list beyond the level of category membership. The primary use of these models, I believe, is in the accident investigation process, and for the organization of safety management systems; both of these topics are beyond the scope of this review.

B. Multiple Factors: The Epidemiological Approach

The epidemiological approach to accidents (Gordon, 1949) draws an analogy between disease and accidents, making the claim that the incidence of and succeptibility to accidents can be understood in the same way as, for example, the incidence of and succeptibility to TB, polio, or syphilis. This approach considers the features of the host (that is, the victim of the disease/accident; eg., age, sex, general health), environment (eg., living quarters, social status, time of year, etc.), and agent (eg., the physical and/or biological nature of the virus, bacteria, poison, etc.) in the description of the circumstances of the disease, with a view toward identifying the factors contributing to the disease and/or identifying the population at risk. This approach has had considerable success; for example, in demonstrating the increased risk of polio during the warm weather months.

In the medical area, the usefulness of the approach is due in large part to the relative ease with which the agent can be identified and understood; it is typically a biological organism whose definition is specific, and whose characteristics and behavior can be observed independently from host and environment. The difficulty which has plagued the adoption of the epidemiological approach for industrial accidents is the problem of identifying and understanding the agent involved. One solution has been to characterize the agent by the type of damage produced; that is, to classify accidents by burns, cuts, falls, breaks, strains, and so on, to various parts of the body (this seems very much to be a medical solution). A second solution has been to

classify the type of energy-implement combination (the source of injury) involved in the accident; for example, mechanical, electrical, or radiant energy emanating from some machine or object.

The agency debate itself has been a source of difficulty for this approach to accidents, and it highlights what may be a major flaw in the analogy between accident and disease. To hold firm to the analogy, characterizing the agent as an energy transfer type rather than a damage type seems to be most appropriate, since both energy and virus (for example) are immediate causes of the illness/accident symptoms. However, the disease agent is never benign, but only more or less malevolent, while the energy source more often than not is benign; that is, it serves its function properly most of the time. The agent problem in the epidemiological approach may not be a problem in principle, but it is a problem in practice, as it introduces a third list of variables for accident research to identify and define, a list that may not exist independently from host and environment variables.

The use of a disease model analogy for understanding accidents has a further shortcoming. Typically, the epidemiologist knows what the disease agent is, and to this extent knows the <u>cause</u> of the disease.* Epidemiology, then, was neither designed nor intended to identify <u>cause</u>; rather, its purpose was to identify (1) the environment that supported the cause, and (2) the characteristics of the persons-hosts who were succeptible to the disease. An epidemiological study does not proceed until the cause (virus or bacteria, for example) has been identified; it cannot proceed because the researchers cannot know which

*See Research Branch note, page 47.

cases/incidents to investigate without this information. As a model for accident research, epidemiology will be appropriate for the two purposes mentioned above, but only when the agent-cause of the accident is understood as well as are the viral and bacterial causes of disease. The systems approach, described in the next section, offers one way to accomplish this level of understanding, by advocating a microscopic examination of man-machine interactions.

The epidemiological approach, however, was a theoretical advance over the previous models of accident causation, in that it explicitly acknowledged the conditional nature of the relationships among causal factors. In other words, the approach recognized, albeit simply, that accidents were an interaction of some sort among three classes of variables, and promoted research and investigation procedures that observed all three types. This research, however, would have to be of immense proportions, since epidemiology could not identify which host, agent, and environment variables might be most promising. To attempt to record everything would be overwhelming, but to sample only a manageable few would always leave unknown questions unanswered. Without specific guidance from the theory (and the theory does not provide this) there is no way to evaluate the adequacy of the research choices that are made.

C. The Systems Approach

The theories and models of accident causation described below are similar to each other in that their general focus in on the details of the interaction between the individual and the task. Unlike previous approaches, which may merely mention that a man-machine interaction exists, the systems approach seeks to describe the psychological processes involved in such an interaction, and to identify the nature of situations in which an accident might be expected to occur. Of central importance are the processes concerned with perception, memory and knowledge, and decision making. Variables which were previously considered central to a theory of accidents (eg., personality type, age, sex, culture, energy type, etc.) have only secondary importance within a systems approach, and have this importance only by virtue of their relationships (if any exist) with the psychological processes of interest. Thus, for example, age might be a relevant systems variable, but only because of its possible correlation with the amount and type of information in memory.

Systems models share a common intellectual heritage from electrical engineering, variously known as control theory, cybernetics, or robotics (Weiner, 1948). The central concept in control theory is the negative feedback loop, which enables the system to incorporate a self-correcting mechanism. The household thermostat is a familiar example of a negative feedback loop; this system takes room temperature as an input, compares this input with the desired room temperature (the standard), and if the input is lower than the standard the system reduces the discrepancy by

starting the furnace. The word "negative" refers to the function of system, which is to reduce the discrepancy between the input and the standard. The concept of a negative feedback loop has been applied to the human system and to other biological systems as well; for example, in matching the visual input to standard features stored in memory in the process of recognizing an object, or in making correct adjustments in the extent, direction, and velocity of an arm movement when catching a ball. A simple diagram of a negative feedback loop is shown in Figure 1 (see next page).

To illustrate the various features of the feedback loop with a human performance example, consider the task faced by a baseball catcher. The task is to match the position of the glove with the final position of the ball. The position of the glove is compared to the position of the ball, and any difference is noted by the comparator. Action is then taken on the glove to change its position (behaviour output affects the environment). Such comparisons and adjustments in glove position are repeated until the positions match. The interesting question for this example is the nature of the standard. For the novice, the standard may be ball position, but with practice at catching a ball the standard can become an estimate of the endpoint of the ball's path, given an estimated speed and angle of flight. The glove is then moved initially to this expected endpoint, and finer adjustments can be made if any subsequent estimate predicts a different endpoint.

The professional baseball catcher (an expert) has at his disposal a set of standards that can be used; for example, he can signal for a

FIGURE 1

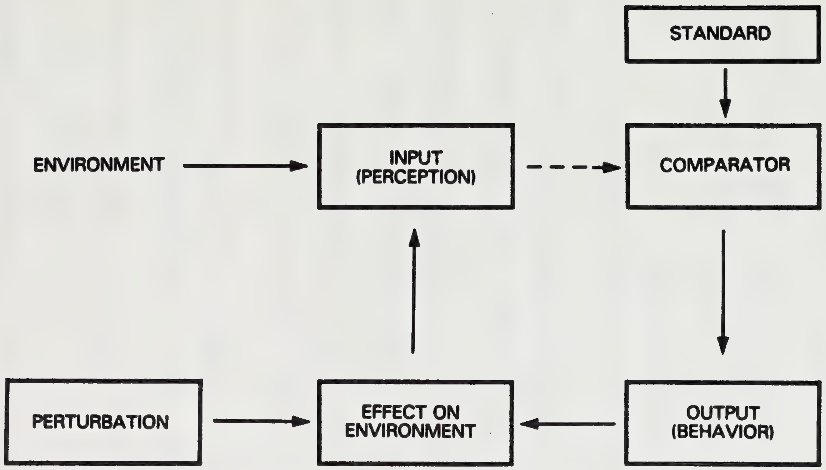

Figure 1. A simple schematic of the negative feedback loop.

low inside curve ball from the pitcher. This becomes the standard for the glove position because the catcher has reason to expect the ball to arrive at that position. This expectation is founded upon the reliability of his machine (that is, the pitcher) to deliver as instructed. A catcher could have a high expectation about one type of pitch (eg., a fastball) but a low expectation about another (eg., a knuckleball). With a higher expectation comes a lower necessity to make adjustments, whereas constant adjustments and constant vigilance are required in order to catch the knuckleball.

The possibility for error in such a system abounds. The input may not accurately represent the environment (a perception error), the standard may not be appropriate to the task (a knowledge error), the output may not meet the requirements of the task (a skill deficiency), and any perturbations in the environment (a gust of wind, or a foul tip, in the baseball example) may require a new standard to be chosen. Any of these possibilities may result in a dropped ball -- an error or an accident. From the systems theory perspective, an accident occurs whenever there is a mis-match between the performance of the machine (the operating system), and the performance of the operator, whether or not damage or injury occurs.

The models described on the following pages all view industrial accidents from a general systems theory perspective. Systems theory focusses upon the interaction, feedback, and adjustment between man, machine, and environment, and is capable of indicating the temporal order of the events that contribute to the accident event.

1. Jean Surry (1969): Human engineering approach

The Surry model consists of two phases for an accident, with each phase containing three psychological components; the perception of events, the understanding of events (cognitive activity), and the behavioral response. Phase one is concerned with the build-up of the danger, and the perceptual, cognitive, and behavioral responses relevant to this danger. Phase two is concerned with the operation of these same three components during what Surry calls the danger release period, that period during which the danger, if not avoided, will produce damage or injury. A schematic diagram of this model appears in Figure 2.

Each component of each phase is described by one or more questions. Questions relevant to the build-up phase begin by asking "Is there any objective warning cue for a build-up of danger?" This question asks only about the immediate state of the environment, and can be rephrased by asking whether or not a perceptible difference exists in the environment between a safe operating state and a hazardous one (that is, a state in which damage or injury is probable if evasive actions are not taken). Close observation of the environment during normal operation would be required in order to determine the existence and nature of the danger cues (experience on the job could in theory provide this information, but it may well fall short in practice). A second implication of this feature of Surry's model is the implicit acknowledgment that danger may have no perceptible cue associated with it; thus, some accidents may be unavoidable, since they occur without warning. The first question of phase two of the Surry model, which

FIGURE 2

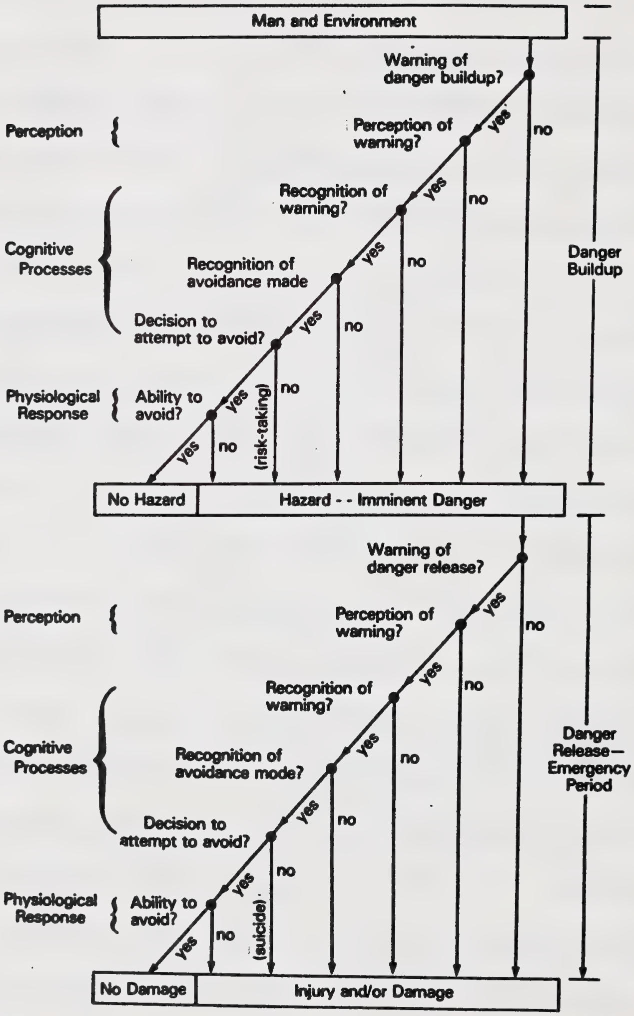

Figure 2. The Surry (1969) model of accident causation.

asks about the presence of a cue that signals danger release, is subject to these same comments.

The second question in each phase asks "If there is a cue, can it be detected by the operator?" This question asks about the perceptual capabilities of the operator with respect to the danger cue. The most basic human factors/senses are involved here; for example, visual acuity, auditory signal detection, kinesthetics, and so on. Also relevant to this question are the effects of 'noise', tasks that demand a great amount of attention, etc. Quite apart from a lack of vigilance on the part of the operator, a danger cue may not be perceived because the human sensory system, in that operating environment, is unable to detect it. Thus, if a danger cue is known to exist, yet noise or attentional overload prevent its detection, instruments that would change or amplify its signal should be installed to make the detection of the cue possible for the operator.

Surry proposes three questions relevant to the cognitive component of each phase, questions that ask about (a) the meaning of the danger cue, (b) the operator's knowledge of avoidance responses, and (c) the decision to avoid or not. To understand the meaning of the danger cue is to know or recognize that the cue, the particular change in the environment, does in fact signal danger. A squeek, a movement, or the absense of a familiar object may be either a known or an unknown danger cue for the operator. Recognition, then, requires that the operator knows what the danger cues are for a particular operation, and knows what danger is implied by each cue. The second question in this set

points out that a knowledge of avoidance behaviors is also necessary. These behaviors may be simple (eg., switch off the machine), or they may be elaborate (eg., shoring up an unstable trench), but probably all responses to danger cues can benefit from training. However, the Surry model makes it very clear that such training in avoidance skills is irrelevant if the danger cues for the operation are either unknown or unrecognized; knowing what could happen is a pre-condition for knowing how to react to possible danger.

The next step, the decision to avoid, is a most interesting feature of the model. It states simply that the operator may choose, on the basis of perceived risk, to ignore potential danger. By the inclusion of a step such as this in an accident model, Surry implies a probabilistic relationship, and not a perfect one, between the danger cue and the subsequent danger release (although this feature of the model is not made explicit). A decision to ignore a danger signal would make sense at this point only if the operator knows that the cue sometimes does not signal an impending accident, injury, or damage. The operator at this step judges the risk, or probability, that the danger release will occur, and may include as a factor in this decision the various costs and benefits associated with the avoidance behavior (for example, shut-down time, loss of production, safety). Also relevant to this decision may be a consideration of the operator's own self-perceived ability to avoid danger release (the final step in phase two) should that become necessary. The speculation here is that an experienced, competent operator may take greater risks during the first phase, believing that he/she is skillful enough to avoid the subsequent

release of danger.

One can conceive of objective risk as the actual probability that danger release is predicted by the danger cue, and subjective risk as the operator's estimate of this probability. Under-estimation, then, will result in more instances of danger release than is warranted by the operation, while over-estimation may result in a slower rate of production due to unnecessary evasive actions by the operator. The variables that affect the estimation of risk and the acceptibility of risk, as well as the estimation of probability in general, have been researched to some extent in the psychological literature (eg., Slovic, Fischoff, & Lichtenstein, 1976; Kahneman and Tversky, 1984). Kahneman and Tversky, for example, have shown that risks are sought or avoided depending upon how the individual thinks of the consequences of the choice; if the probable outcome is described as a loss, people prefer risk, but if the outcome is described as a gain people avoid risk. However, a theory of decision and risk that would contribute directly to the understanding of risk-taking in an industrial setting has yet to be developed (although the potential is there for a useful extension of these concepts into accident research).

The behavioral component is the concern of the final question of each phase; "Is/can the action taken succeed in avoiding the danger?" Motor skills are clearly implicated here (eg., quickness, agility, accuracy), but the more subtle implication of the Surry model is that on occasion even the correct behavioral response may fail to avoid the danger. The notion of random variability or random error (in the statistical sense) is a basic part of the model; it asserts that all

occasions of the same behavior are not identical in all respects, but that they vary somewhat from one time to the next in terms of, for example, speed or accuracy. A danger that can be avoided by a reaction time of one second or less can be avoided most of the time, but not all the time, by a person whose reaction time averages 900msec.; the variability of response speed may be such that reaction time exceeds the critical time of one second 5% of the time. The resultant injury or damage in such a case would be due to the variability or error that is inherent in the person's motor response system. It is error that cannot be controlled by the individual.

In a similar manner, one can conceive of the variability that is associated with the danger release mechanism. For some particular hazard, the danger cue may signal that danger release will occur in two seconds, on average. But the variability in danger release time may mean that on rare occasions only one and one-half seconds are available to make the necessary avoidance response, and this amount of time may be less than the time required to avoid the danger release. This sort of variability could be reduced through improved machinery or improved maintenance, or through improved skill on avoidance tasks, in some cases, but the concept of the inherent variability of systems suggests that there will be a lower limit, and that beyond this point no further amount of time, effort, or money can eliminate this variability of the system. It is in this respect that one can truly say that "accidents will happen". The question is how much variability can be tolerated within the system.

2. Andersson et al. (1978): An extension of the Surry model

Andersson et al. (1978) made use of the Surry model, and of the questions posed in it, in an analysis of the causes of sixty industrial accidents, and concluded that a sizable deficiency existed in the list of questions included in the model. They point out, correctly, that the Surry model deals explicitly with the operator, but not with the operating process (that is, with the machine and its surround). What Surry includes implicitly in her model, Andersson et al. make explicit by the addition to her model of a prior set of questions/steps that concern the source of and the perceptibility of the danger cue, the fluctuations (variability) within the operating system, and the potential for controlling and/or reducing these fluctuations to the point at which they are compatible with the fluctuations in the human operator's behavior. By directing attention to the work setting at the same level as Surry addresses the human/psychological processes, these authors provide a useful and compatible completion for the model developed by Surry (see <u>Figure 3</u> for a diagram of their addition to the Surry model).

Several aspects of the new set of questions proposed by Andersson et al. (see <u>Figure 3</u>) have been dealt with in my discussion of Surry, and will not be repeated here. Unfortunately, Andersson et al. are at times less than clear about the meaning of some of their questions, and as a result my explication of the steps in their expanded model may not accurately describe their vision of the model. The Andersson addition begins with a controllable system (an uncontrollable system,

FIGURE 3

S.I.C.

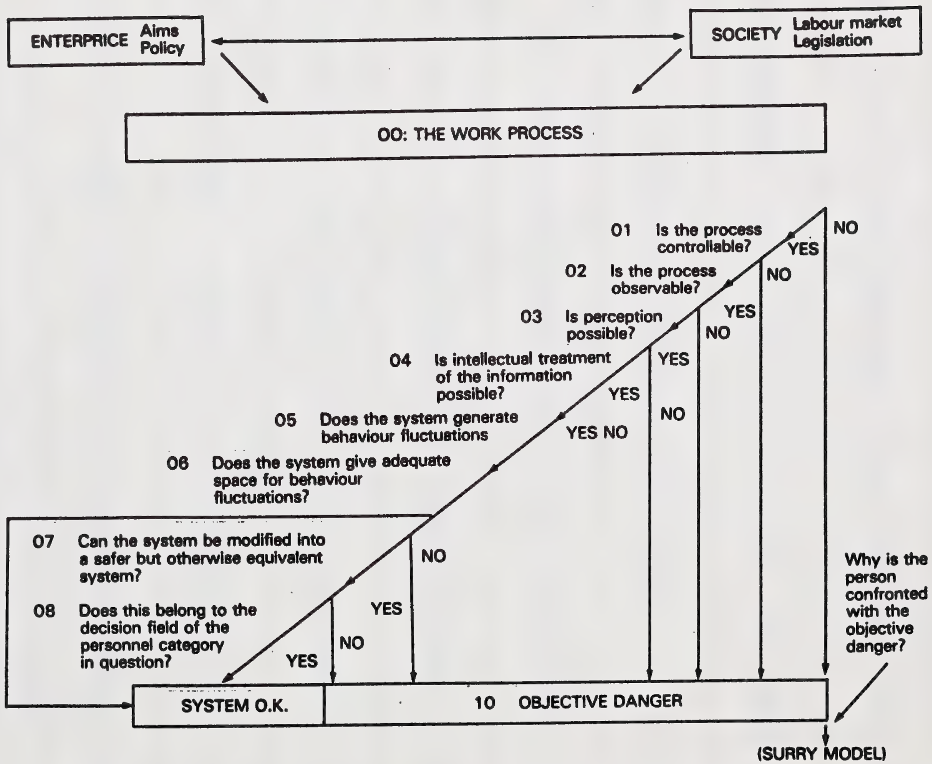

Figure 3. The Andersson et al. (1978) addition to the Surry model.

for example, lightning, cannot be handled by this initial phase of the model), and first asks if the system is observable, either technically (that is, with instruments) or perceptually (that is, with the human senses). The question "Is perception possible?" asks about background noise, lighting, barriers, and so on, which may obstruct perception of the work process. The following, related question asks if the person is more or less prepared to observe the operating system; that is, does the operator know how the system works, what sort of noises or movements, etc., it makes? Related considerations at this point of the analysis concern the degree to which the operation promotes fatigue, stress, or decreased vigilance that may interfere with accurate system observation. Note that these questions and concerns are similar to those prompted by the first step in the Surry model, except that for Andersson et al. attention is directed toward the whole system rather than toward a particular danger cue only.

The next two questions ask about operator performance variability; how much is there, and does the operating system provide adequate time and space to accomodate these behavioral fluctuations. If it does, then the operating system can be considered to be a safe one; if not, then system modifications (of either machines or procedures) must be developed that will safely allow for the expected range of behavioral variation. It is important to note, however, that a safe system need not be danger-free; a safe system is one in which the danger is known, observable, controllable, and minimized and/or avoidable because it is designed with a certain degree of human interaction variability in mind.

The remainder of the Andersson et al. model deals with the operator's avoidance responses, in a manner similar to the Surry model.

For the Surry model, and its extension by Andersson et al., the key to understanding the causes of industrial accidents rests with two types of knowledge: (1) knowing in detail the physical operation, the variability of tools, materials, machines, and procedures, and (2) knowing the perceptual and motor capabilities of the operator within the operation setting. In short, considerable research on any system is required in order to understand how it normally works, and how it can go wrong.

3. Hale & Hale (1970): Expectancy, skill, and decision

Hale and Hale (1970) consider an accident to have occurred when an individual fails to cope with, or fails to respond appropriately to, the true state of affairs; whether an injury or damage result or not is irrelevant to their definition. Like Surry, Hale and Hale focus their model on the ongoing operation, on the interaction between the operator and the operating system. They make this focus very clear by describing the model as a closed loop. Essentially, their feedback loop consists of the following elements; (1) the situation is perceived, (2) the information is processed, (3) the operator acts such that the situation is changed, (4) it is then newly perceived, processed, and responded to, and so on. A diagram of the Hale and Hale model is shown in Figure 4.

Presented information consists of the information about the state of the operating system that is available to the operator. This

FIGURE 4

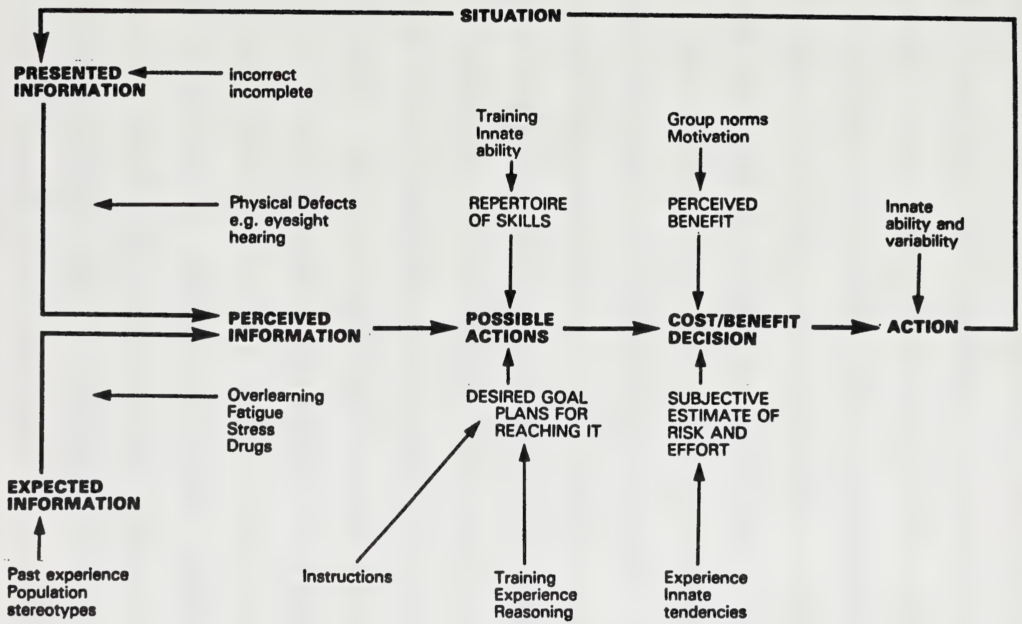

Figure 4. The Hale and Hale (1970) model of accident causation.

information may be incorrect (eg., because of faulty instruments) or it may be incomplete (that is, some information about the system may be unavailable to the operator; it may be imperceptible), and both of these possibilities could result in performance errors. In this respect the Hale and Hale model differs little from the Surry model, except that Surry is more comprehensive on this aspect of the process.

But Hale and Hale also give equivalent status to the role of expected information as a contributor to what is perceived by the operator about the operating system. They note that expectancy often guides our perception and selection of information. An expectancy is more than the knowledge of what information the system might present; it also contains the probability or likelihood that a particular state of affairs will exist. An expectancy predominantly consists of the usual or typical state of affairs, and may contain little information regarding system aberrations, or low probability events. To the extent that an expectancy guides perception, then, two types of error can occur: (1) the operator may "perceive" that a typical feature is present when it is in fact absent, and (2) the operator may fail to perceive the low probability features that are on occasion present. In addition, an expectancy could fill in the gaps that exist when the presented information is incomplete. Hale and Hale propose that over-reliance on expectancy information at the expense of presented information would be especially likely for routine and repetitive tasks (tasks with low variability from one time to the next), and when the operator's state is such that attention to or the ability to perceive the presented

information is impaired (for example, stress, fatigue, medication, etc. may make vigilance too effortful or even impossible).

Behavioral decisions follow from the perceived information, and training, experience, and knowledge of the operating system are important factors at this point. Perceived information indicates the state of the operating system; if the system appears to be normal, normal actions are taken. Training and experience typically provide knowledge about the normal actions, and accidents that occur under these conditions might be attributed to insufficient knowledge about appropriate actions. The response to an abnormal state of the system requires different knowledge and/or skills that may or may not have been provided by training or past experiences. In agreement with Surry, Hale and Hale point out the necessity for the operator to know about the operating system, both its typical state and its possible aberrant states, and to know the actions appropriate to each.

Hale and Hale include a decision step with respect to the action taken by the operator. In addition to the considerations included in the Surry model (those based upon the risk within the system), Hale and Hale suggest some <u>extra</u>-system factors bearing on risk and decision. These consist of group norms and motivational factors. While Hale and Hale do not elaborate on the definition of these factors, I believe that they wish to include here a consideration of how the operator's acceptable level of risk tolerance is affected by (1) the level of risk acceptable to co-workers, and (2) the operator's judged value of lost time versus production speed, for example, as a motivation for changing

his risk tolerance level.

Finally, according to the Hale and Hale model, errors may occur due to variability in the appropriate response to the system. Hale and Hale make explicit here what Surry only implies, and my comments on Surry with respect to performance variability apply equally well to Hale and Hale.

A change in the operating system follows action, and brings the operator back to the information stage of the model. Hale and Hale include a monitoring function in the loop back to the situation; the operator will periodically observe the operating system to see that a normal state of affairs still exists. The frequency of monitoring, it is proposed, will be lower for well practiced tasks (i.e., routine tasks), and higher for unpracticed tasks. Although Hale and Hale do not mention this, the implication is that expected information becomes the only source of perceived information in between monitoring occasions. Accidents are likely to occur between monitorings, then, because the operator at this time is performing the routine actions regardless of the true state of affairs. System aberrations can only be responded to if they occur when the operator is monitoring the system. The frequency with which the system is monitored, therefore, becomes an important factor in the causation of accidents.

Despite the differences in the manner in which Surry and Hale and Hale schematize their respective models, their views on the causes of accidents and the process by which accidents occur are highly compatible. The Hale and Hale model is distinguished from the Surry model, however,

in two major respects: (1) in their inclusion of expectancy as an equal contributor to perceived information, and (2) in their proposal that observation of the operating system (monitoring) may be periodic rather than continuous. Several questions are raised by these new proposals; for example, what determines the relative power of expected versus presented information in generating perceived information, and how could the appropriate rate of monitoring be determined for a particular operating system?

4. Adaptations of the Hale and Hale model

Smillie and Ayoub (1976) expanded the Hale and Hale model to include specification of the input and output possibilities at each stage. Their most notable elaboration of Hale and Hale consists of a description of the possible combinations of presented, expected, and perceived information. When presented information is equivalent to both the expected and perceived information, the system is operating normally, and normal operating activity follows. But three other possibilities result in a perturbation of the system, requiring some adaptive response that is probably non-routine and less well learned: (1) presented information may not be equivalent to the expected information, and is perceived to differ, (2) presented information may be equivalent to expected information, but this equivalence is not perceived, and (3) presented information may not be equivalent to the expected information, and this discrepancy is not perceived. In the first case the operator knows that a system aberration exists, and takes adaptive actions. In the second case the operator believes that an

aberration exists when in fact the system is operating normally, and takes "adaptive" action that is inappropriate to the situation. And in the third case the operator fails to notice that the system is not operating normally, and so fails to take appropriate evasive action. (Please note that the Smillie and Ayoub elaboration of these three possibilities, as described in their paper, contains much ambiguity. While the above interpretation of what they contribute is consistent with Hale and Hale, I may have mis-represented their intended meaning.)

Smillie and Ayoub make use of their elaborated schematic of the Hale and Hale model by developing a computer simulation of the process based upon it. While their purpose was commendable, their implementation of the simulation did not do justice to the complexities of the model: The variables included in the simulation represented the important psychological processes only at the grossest level, if at all (for example, experience could have two values, present and absent), and most of the variables included were secondary to the model (for example, time of day, temperature, etc.). Smillie and Ayoub were correct to attempt a simulation based upon a model such as Hale and Hale; the systems approach is ideally suited to computer simulation applications because it specifies both the time-course and the details of a man-machine interaction.

Corlett and Gilbank (1978) adapted Hale and Hale for a different purpose, namely, as a tool for the investigation and analysis of accidents. Corlett and Gilbank present a partial list of questions to be asked and answered during the course of an investigation, a list

that focusses primarily on the sequence of events in Hale and Hale. They ask about the completeness and correctness of the information presented, and about the physical objects that may prevent perception of these. They also attempted to obtain information relevant to the operator's expectancies by asking whether and how often similar events had occurred, whether the operator was aware of these previous incidents, and so on. While these questions are far from adequate for the task, when accident investigations begin only after the fact, such questions may be the only source of information about the operator's expectations, given that baseline data for the characteristics of the operating system are unavailable. Corlett and Gilbank's attempt to adapt a system theory for practical application to investigation was an appropriate and noble one, but it underscores the necessity for a detailed understanding of the normally functioning operating system (a need that is clear from the models of both Surry and Hale and Hale).

5. J. Saari (1977): An example of theory-directed research

Saari (1977) presented a simple information processing model of accident causation (one that is simple, yet compatible with the ideas contained in Surry and Hale and Hale) that focusses primarily upon the complexity of information processing required during the task as an important mediating factor. Saari noted that the information handled by the operator during a task can be divided into two parts, (1) that relevant to the productive task, or the primary task, and (2) that needed for keeping potential dangers under control, or the secondary task. Saari proposed that an increased difficulty in either the

primary or secondary task could result in more information than the operator can handle (that is, the information will exceed the person's capacity). Due to the priority of these two sources of information, it is secondary task information processing that will be reduced when the attentional capacity is exceeded, and accidents will become more likely.

Saari proposed that information is likely to exceed capacity when the primary task is irregular (that is, non-routine, such that practiced skills become largely irrelevant), and when the primary task is complex, requiring large amounts of information. On the basis of these theoretical considerations, Saari predicted a greater frequency of accidents for jobs that (1) require continuous planning by the operator, (2) require continuous movement from one location to the next, and (3) are performed in a wide variety of settings. Saari reports results consistent with these predictions; accidents were more frequent for the group whose duties were characterized by these three features (for example, maintenance workers).

Neither the model nor the research presented by Saari are very sophisticated. Nevertheless, it illustrates an important benefit of the systems approach to the causes of accidents; namely, that the systems approach can facilitate the generation of relevant testable hypotheses to a greater extent than did the previous, less complex, models.

D. Summary and Conclusions

Theories of accident causation have developed considerably during the past sixty years. Early formulations were simple single-factor theories that satisfied the hopes of those who would reduce accident rates, but that failed to increase our understanding of the accident process. Two-factor theories, which considered two possible causes instead of one (eg., an unsafe act, or a mechanical hazard) directed attention more evenly between the operator and the immediate work environment, but failed to recognize the complexities of the interaction between the two. The epidemiological approach further subdivided the environment into accident agent and other environment factors, but again did not fully appreciate the complexities of the accident process. These latter theories proposed multiple possible causes, but never incorporated the idea that these causes may contribute interactively rather than additively.

These theories and models failed in another respect also. The variables suggested to be important for determining cause were largely secondary level variables; variables that were correlated, or that might be correlated with accident occurrence, but that could not be the direct cause of the accident. These theories and models did not begin with an analysis of the accident event itself and describe how it was that an error of some kind might be made, and the result of this oversight was that primary factors were largely overlooked or were greatly simplified. The descriptive information available from accident reports facilitated this treatment of and understanding of accidents

in terms of secondary factors because these reports contained for the most part general information on the state of the operator and the machine, and rarely could provide the details of the accident process (previous theories did not direct attention to the process.)

The systems theory approach to accidents emerged from a consideration of the processes involved in man-machine interactions. Systems theory begins with a detailed analysis of machine and human behavior as an interactive system, and from this perspective it became important to know how the machine behaves (its regularities and irregularities), how the operator behaves (sensory, cognitive, and motor response capabilities), and whether the machine is compatible with these human limits. In general, systems theory approaches defined work place accidents and errors an an incompatibility or a mis-match between the human behavior and the machine behavior. From this point of view, the primary human factors could be identified. These included perception and detection of state-change information, recognition of this information, knowledge of its meaning, knowledge of the appropriate response, decision making with respect to risk and probability, and response speed and accuracy. In contrast, the factors identified in previous approaches (eg., epidemiology) are secondary, in that they may be related (causally or otherwise) to these primary processes. For example, age is very likely negatively related to response speed and positively related to knowledge, noise may be related to perception, and so on. Within the systems theory approach, epidemiological methods may have a value in identifying these secondary factors once the primary cause becomes known.

The systems approach to industrial accidents is becoming more and more accepted within the discipline in recent years, particularly in Europe (in addition to the references in Section C, refer to Leplat (1983) and Singleton (1983)). In North America the acceptance of a systems approach appears at present to be piece-meal borrowing rather than total adoption. For example, Conway and Sanders (1980) discuss the concept of human error, and Arndt (1980) discusses in general terms the value of a focus on the man-machine interaction, but these efforts do not include the detailed analysis that is possible from a systems theory perspective. This incompleteness is probably due to the greater concern in North America with accident investigation and prevention (that is, applied concerns) in response to government regulations and control, and a lesser concern with theory and basic research into the accident process. Nevertheless, these writers have made progressive suggestions concerning accident research that are clearly guided by systems theory. Conway and Sanders, for example, suggest that "it is more productive to seek the causes of human error than to attribute the cause to human error" (p. 91), and Arndt (1980) strongly advocates research that will provide the "basic data on capabilities, frequency of errors, and normal variations . . ." (p. 111), as well as other research on topics basic to the systems approach. There is every reason to predict that systems theory will be the major guide for the study of accidents and the prevention of accidents for the future.

As a general conclusion, then, the best current approach for understanding industrial accidents is the systems theory approach, in

its various forms. Choosing from the Surry model, the Hale and Hale model, or some variation or combination of systems models is at this point, I think, largely a matter of personal preference; the amount of research and applied experience with these models is too low to support an informed choice. Each has its merits and its omissions, and future use and development of systems models will likely indicate the particular approach that best serves the investigation, research, and prevention requirements of the industrial accident community. In the remainder of this review I will briefly suggest some of the implications of the systems theory approach for accident investigation, accident prevention, and accident research.

1. Implications for Investigation.

For the cause of an accident to be identified, systems theory requires that the operating system, both its regularities and its aberrations, be known. In particular, one must know the infrequent operating characteristics of the system, whether the operating system consists of a highly automated machine or a warehouse. The relevant question is how often does a particular danger cue occur within the system, and how often does it precede an accident. An investigator would want to know, for example, how often a machine squeaks, and how often this irregularity in the system is associated with an accident, a near-accident (avoidance by the operator), or a non-event. In the warehouse, for example, one would want to know how often boxes are used in place of ladders, how often the box wobbles when stood upon (the danger cue?), and how often injury or damage results from such use.

This type of baseline frequency information could be obtained through systematic observation of the operating system under normal conditions, or perhaps by having workers report on all instances of perceived system aberration ("close calls"). The systematic observation of an operating system need not be costly and time consuming. Even if implemented on a modest scale, for example, observations on one day per week, or the observation of a few selected man-machine systems, these new investigation practices would contribute to the understanding of accidents from a systems theory perspective.

The need for appropriate base rate information exists regardless of the nature of the theory that guides the investigation. Even when the investigator only obtains data about secondary factors, baseline data of the type described above is needed in order to identify the existence and direction of the relationship between accident occurence and the secondary factor.

Consider the hypothetical accident data shown in Table 1, which show the presence or absense of variable X for 100 accidents of some type. Example 1 indicates that X (let's say that X is noise level in excess of 90dB) is present in 65% of these cases. While one might be tempted to conclude that noise contributes to the accidents, these accident data, by themselves, cannot support this conclusion. Baseline data are needed for this task, and three possibilities are provided for this example. For baseline "A" one can conclude that accident rate is related to high noise levels, but for baseline "B" one must conclude that no relationship exists. However, if baseline "C" is

Table 1

Example 1.

		Value of Variable X present	absent	Relationship
Accident Sample		65%	35%	
Baseline Sample	A.	35%	65%	Positive
	B.	65%	35%	None
	C.	90%	10%	Negative

Example 2.

		present	absent	
Accident Sample		50%	50%	
Baseline Sample	A.	20%	80%	Positive
	B.	50%	50%	None
	C.	80%	20%	Negative

Table 1. Examples of hypothetical accident data to illustrate how the conclusions regarding the contribution of some variable to the accident are affected by the nature of the baseline data.

obtained, one must conclude a negative relationship between noise and accident rate; that is, the relationship indicates that low noise levels may contribute to accidents. The precise conclusion that one can reach depends upon the nature of the baseline data; if these data consist of "close calls", the conclusion for "C" might be that while the noisy environment appears to be more dangerous, avoidance of accidents is more likely. Example 2 in Table 1 illustrates the same three types of conclusion for the case where the accident data by themselves seem to indicate no relationship.

2. Implications for Prevention

Accident prevention efforts can be directed at either the machinery or the operators of the machinery. With respect to the machine, systems theory advocates increasing the reliability and decreasing the fluctuations in machine performance. Proper maintainence and an appropriate equipment replacement programme can accomplish this. But systems theory suggests that something else is very important also, namely, that an operator must be able to detect those aberrations that cannot be eliminated by maintainence or replacement. The problem becomes one of designing a machine that gives a clear warning of impending danger, either through direct sight and sound, or through the use of equipment that can detect the danger cue for the operator. A safe machine, then, is one that gives sufficient warning, but the warning must also mean that real danger is very likely. A danger cue that predicts danger 80% of the time is far more efficient than one that predicts only 20%.

With respect to the human operator, systems theory suggests many

ways to affect the operator's safe and efficient task performance. One focus of systems theory that may be very relevant for accident prevention is its concern with a variety of cognitive factors -- recognition, judgment, knowledge, etc. The basic question is, does the operator know all that needs to be known about the operating system in order to recognize danger cues, recall the appropriate response, and make an informed choice with respect to the risk involved. Most safety training programmes will include instruction on how to do the task under normal operating conditions, but might underemphasize information about system aberrations. Workers might benefit a great deal by being told what danger cues he/she might encounter on the job. Essentially, this would involve discrimination training, having the operator discriminate between normal and abnormal operation states, and between safe and dangerous states.

Accidents could also be prevented if the operator knew how often these danger cues were likely to occur, and the extent to which the cue predicted ensuing danger; this amounts to explicit instruction regarding the information value of rare events, in order to counteract the tendency to ignore or fail to recognize the significance of such events. Special training should also be provided on the avoidance skills required in potentially dangerous situations. I suspect that job training time spent on normal versus abnormal operation states is roughly equivalent to the actual ratio of the occurence of these states. Systems theory, however, would advocate a greater proportion of the training time be allotted to the less frequent occurences, since normal

operating procedures can be learned on the job in relative safety, while it is clearly dangerous to try to learn responses to aberrations on the job. Systems theory highlights the importance of knowing what to do when things go wrong, and the potential difficulties that exist in gaining such knowledge. Safety training, then, should strive to create in the worker these alternate performance skills; in terms of Hale and Hale's concept of expectancy, the operator should have two equal expectancies for any task, one for normal conditions, and one (or one set) for aberrant conditions.

This recommendation, then, is for specific instruction regarding danger cues and system abnormalities. This could be accomplished in many cases through the use of system simulators (cf., flight simulators). A simulation could easily vary the frequency and diagnosticity of danger cues and system fluctuations to levels above and below their natural values, and thereby provide the experience of accidents and dangerous incidents in complete safety.

3. Implications for Basic Research

The implications of systems theory for accident investigation and prevention require the support of basic research into the accident process. Basic research is needed to identify and direct the changes to be made and the methods to be used in these applied areas. Methods for observing and recording the operating system, and for determining the danger cues, must be developed. Also, basic research should direct attention toward the human limits with respect to perception, recognition, recall, risk judgments, and performance in both experimentally

controlled settings and normal operating conditions. This research might ask, for example, whether a particular danger cue can be recognized in a variety of settings, or what factors contribute to the memorability and recognition of rare but potentially dangerous circumstances, and what sort of training interventions could increase the memorability of such conditions.

Basic research could also direct attention toward the distinction between primary and secondary human factors; in particular, the research might determine the relationship between secondary human and environment factors and the individual's perceptual, cognitive, and performance abilities. More complex research questions also suggest themselves. For example, to what extent can operators compensate for the presence of one debilitating influence by increasing the efficiency of some other primary process? can this "compensation" skill be taught? etc.

There are very many research questions that can be asked, and many of these are necessary if systems theory is to be a useful tool for accident investigation and safety training. It is for this reason, above all others, that the systems theory approach to accidents is the best currently available; systems theory provides research direction.

Research Branch Note

In the epidemiology of diseases, the general cause of the disease is known in the sense that the investigator assumes the cause to be an infectious agent (i.e., bacterium or virus) or, in the case of occupational illness, a substance to which the population of interest may be exposed in the workplace (e.g., vinyl chloride monomer or asbestos). However, the precise nature of this causative agent does not have to be identified prior to conducting an epidemiological study.

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